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短　報

Tension wood anatomy in artificially induced leaning stems of some tropical trees

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数種の熱帯樹木における人為的樹幹傾斜後の引張あて材形成の特徴

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Key words: Tension wood, tropical trees, *Hevea brasiliensis*, *Hopea odorata*, *Shorea leprosula*

キーワード：引張あて材，熱帯樹木，*Hevea brasiliensis*, *Hopea odorata*, *Shorea leprosula*

1. Introduction

In a leaning tree stem it generally forms reaction wood (Dadswell and Wardrop 1949). In the process of reaction wood formation the stem recovers to the original upright position. In broad-leaved trees reaction wood is formed in the upper (or tension) side of the stem, which is termed tension wood.

So far as the authors are aware, researches of tension wood have exclusively been carried out for temperate zone trees with limited reports of tropical trees. Wardrop and Dadswell (1955) studied characteristics of tension wood including both temperate and tropical trees which were indigenous to Australia.

From the view point of tropical wood utilization, it is important to study tension wood characteristics because it is categorized to be a defect for wood utilization. As the first step of tension wood research of tropical trees, some characteristics of tension wood which was induced through the experiment of artificially tilted or leaning stems were studied.

Three species, *Hevea brasiliensis* (para rubber, Euphorbiaceae), *Hopea odorata* and *Shorea leprosula* (Dipterocarpaceae) grown in Peninsular Malaysia were selected. *Hevea* is one of the common plantation species in Southeast Asia. Although it is the main purpose of plantation to get latex, para rubber wood is also utilized in wood industries. One serious problem of para rubber wood utilization is the low recovery ratio. Nobuchi preliminarily surveyed the situation of para rubber processing factory in southern Thailand. Only about 30% of logs transported from plantation sites to the factory was utilized for the end uses. The main factor was considered because it included much amount of tension wood which caused warping and twisting in drying process (Côté et al. 1965). It is important to get the fundamental information to minimize the degree of the development of tension wood in plantation stage.

Hopea and *Shorea* belong to the family Dipterocarpaceae which is the typical and one of the dominant groups constituting tropical forests of Southeast Asia. They are the important candidates for the future plantation species. The report of Wardrop and Dadswell (1955) does not include the species of Dipterocarpaceae. The research of tension wood anatomy of those species is very much necessary.

2. Materials and methods

2. 1. Materials

Three-year-old saplings planted in the experimental forest of Universiti Putra Malaysia (UPM) were used.

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Table 1 Descriptions of sample trees.

Species and Tree No. (abbreviation)	Height (m)	D. B. H. (cm)	Height of Knife marking (m)	Leaning
Hevea brasiliensis				
Tree No. 1 (HB1)	6.3	6.0	1.4	weak
Tree No. 2 (HB2)	7.8	6.0	1.3	strong
Hopea odorata				
Tree No. 1 (HO1)	4.8	4.5	1.4	weak
Tree No. 2 (HO2)	5.6	5.0	1.3	strong
Shorea leprosula				
Tree No. 1 (SL1)	5.6	4.5	1.2	weak
Tree No. 2 (SL2)	6.5	5.8	1.3	strong

The descriptions of sample trees are listed on Table 1.

On May 18, 2000 two of each species were artificially tilted by using rope (Photo. 1). One was weakly (about 10 degrees) and the other was strongly (about 30 degrees) bent. Just after the leaning of the stem, knife marking (Fujiwara 1992, Ogata et al. 1996) was performed on upper, lateral and lower sides of the stem at the level of breast height. On August 15, 2000 all treated trees were felled. Wood blocks of 40 cm length including the portion of knife marking were collected for the experiments. Air dried 2 cm thick disk including marking portion and 2 cm disk 15 cm above the marking position fixed with 3% glutaraldehyde were mostly used for the analyses.

2. 2. Methods

2.2.1. Observation of eccentric growth

Transverse sections cut at the center of knife marking were ground with an orbital sander. Radial growths on tension (upper part of stem), lateral and opposite (lower part of stem) sides were observed.

2.2.2. Light microscopy

In a disk fixed with 3% glutaraldehyde, small wood blocks (1 x 1 x 2 cm) were cut in tension, lateral and opposite sides. 20 μm thick transverse sections and radial longitudinal sections were cut using a sliding microtome. Counterstaining with safranine and fast green was applied. Zinc chloride-iodine was also used especially to observe gelatinous(G)-layer.

2.2.3. Quantitative analysis of anatomical characteristics

Average vessel area (μm^2), vessel density (No. / mm^2)

Photo. 1 Sample trees showing artificially leaning stem (*Shorea leprosula*). (a) Weakly leaning, (b) strongly leaning.

Photo. 2 Transverse sections showing eccentric growth of weakly leaning stems. (a) *Hevea brasiliensis*, (b) *Hopea odorata*, (c) *Shorea leprosula*. *T*: tension side, *L*: lateral side, *O*: opposite side.

Photo. 3 Transverse sections showing eccentric growth of strongly leaning stems. (a) *Hevea brasiliensis*, (b) *Hopea odorata*, (c) *Shorea leprosula*.

Photo. 4 Enlargement of transverse sections of leaning stems. (a) *Hevea brasiliensis*, (b) *Hopea odorata*, (c) *Shorea leprosula*. Arrow heads indicate the boundary between normal wood and tension wood.

Photo. 5 Light micrographs of transverse sections showing anatomical characteristics (safranin and fast green staining). (a) *Hevea brasiliensis*, (b) *Hopea odorata*, (c) *Shorea leprosula*. Arrow heads indicate the boundary between normal wood and tension wood.

Photo. 6 Light micrographs of transverse sections showing normal wood (control) (Safranine and fast green staining). (a) *Hevea brasiliensis*, (b) *Hopea odorata*, (c) *Shorea leprosula*.

Photo. 7 Light micrographs of transverse sections showing tension wood (safranine and fast green staining) (a) *Hevea brasiliensis*, (b) *Hopea odorata*, (c) *Shorea leprosula*. Arrow heads indicate G-layer.

Photo. 8 Light micrographs of transverse sections showing tension wood (zinc chloride-iodine staining). (a) *Hevea brasiliensis*, (b) *Hopea odorata*, (c) *Shorea leprosula*. Arrow heads indicate G-layer.

Photo. 9 Light micrographs of radilal-longitudinal sections showing inner layer of fibers stained with zinc chloride-iodine (arrow heads). (a) *Hevea brasiliensis*, (b) *Hopea odorata*, (c) *Shorea leprosula*.

Photo. 10 A sample tree of strongly leaning stem from which a new shoot came out (*Shorea leprosula*).

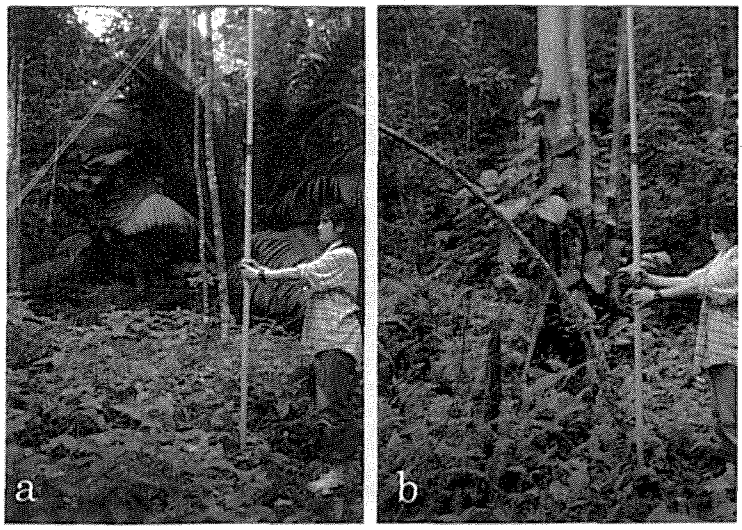
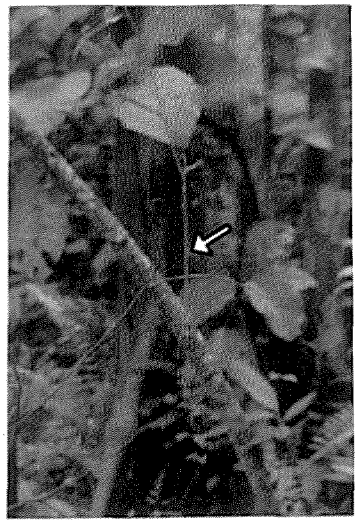


Photo. 1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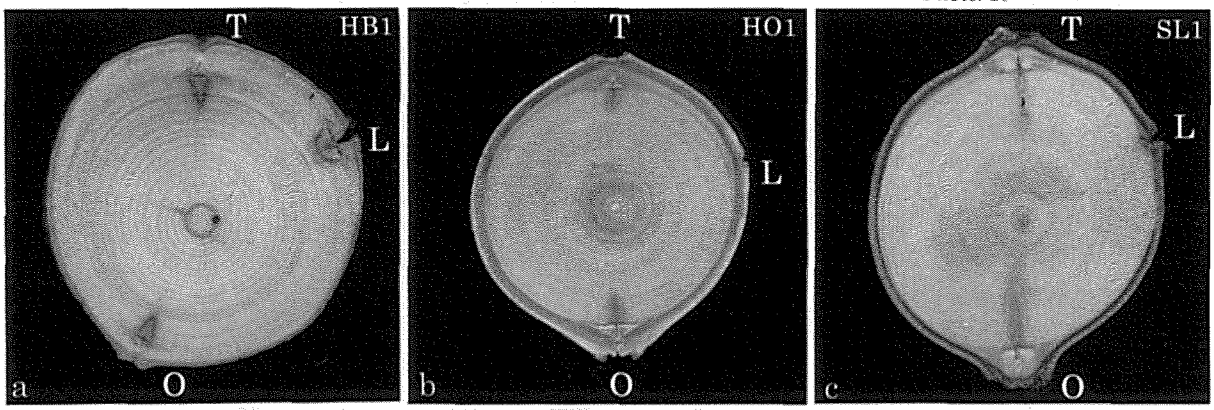

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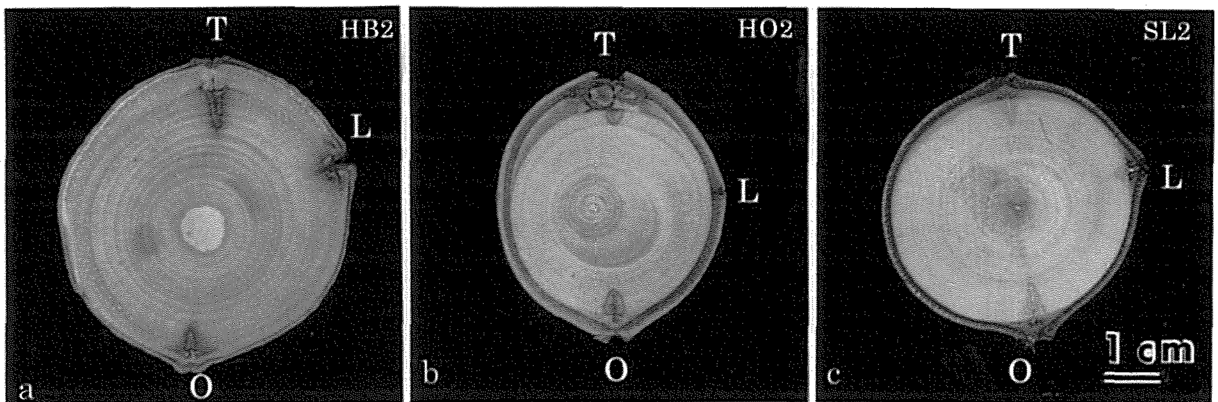

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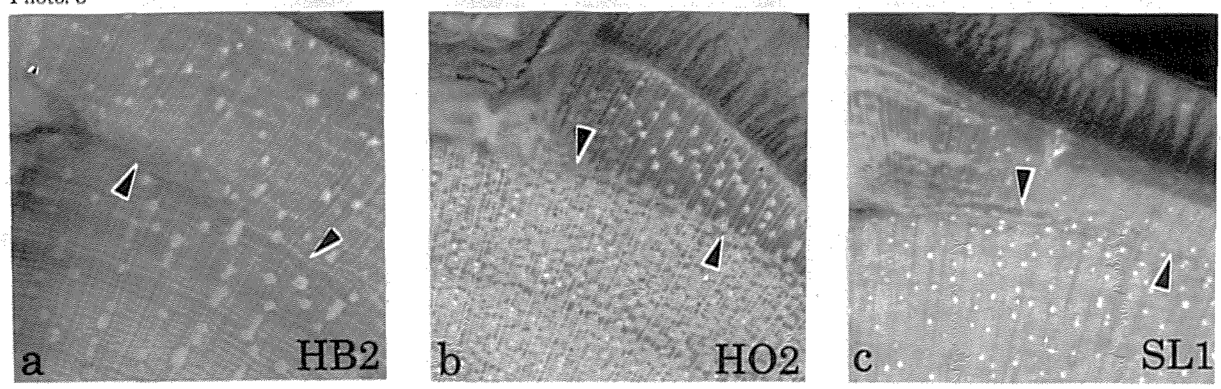


Photo. 4

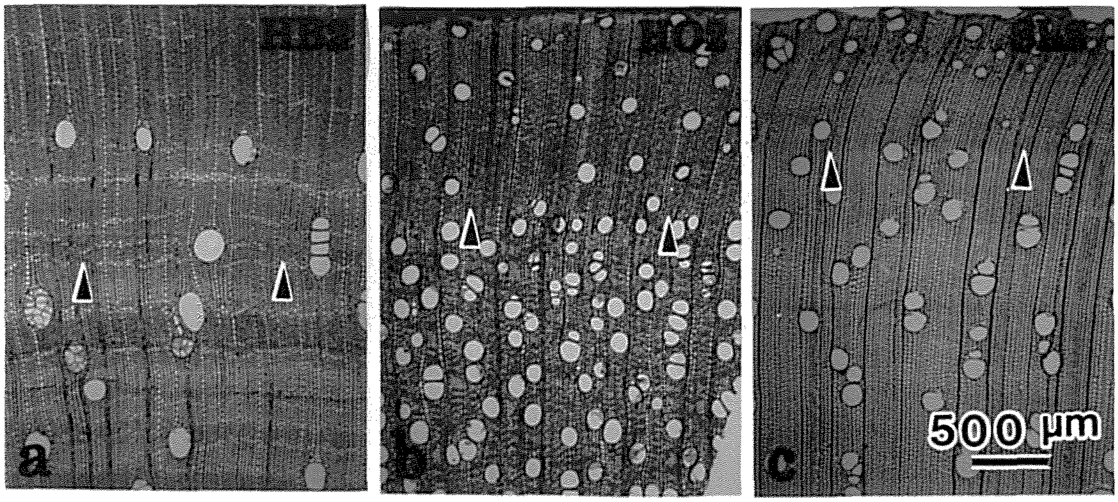
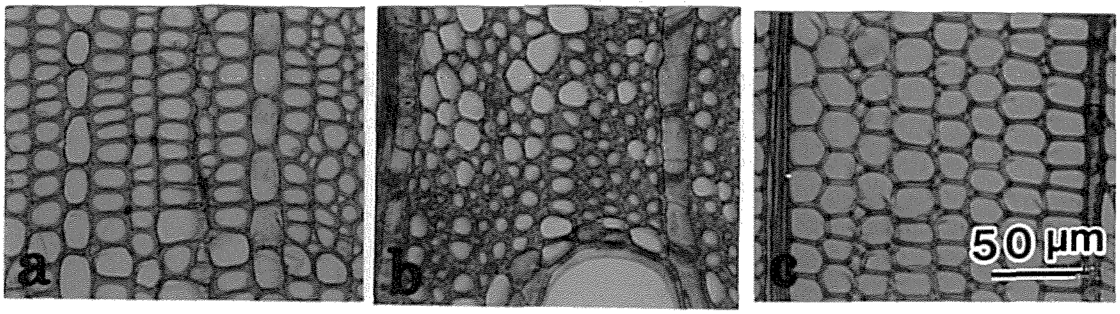


Photo. 5



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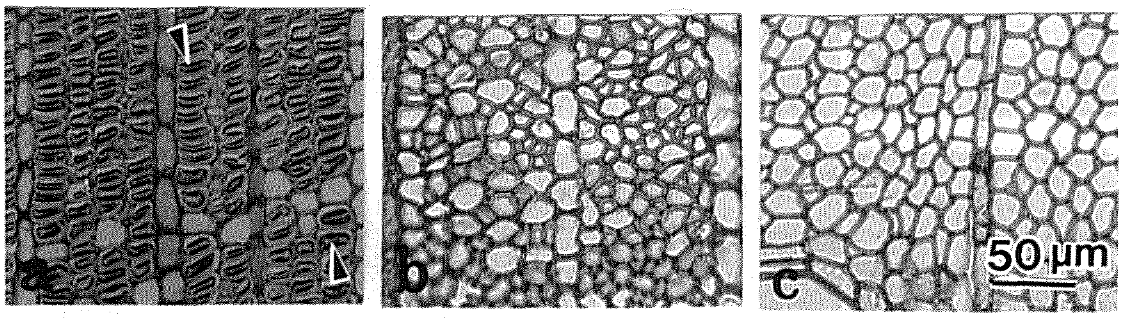

Photo. 7

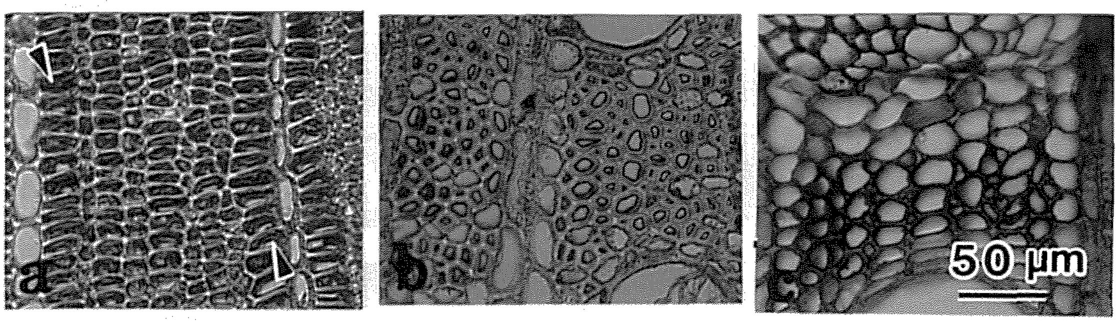

Photo. 8

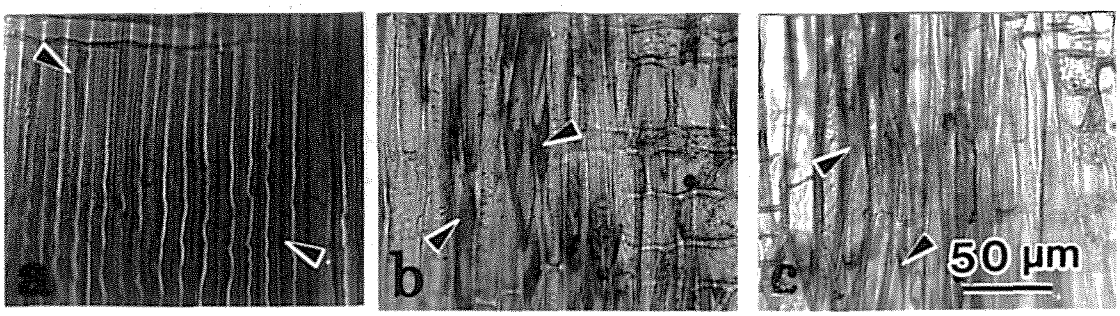

Photo. 9

and percentage of vessel area were measured by a computer equipped with "Image tool" as a software.

3. Results and discussion

3. 1. Eccentric growth and macroscopic features of tension wood

Radial growth on tension, lateral and opposite sides after leaning of stems was observed. Photos. 2 and 3 show the transverse sections at the height of knife marking of weakly leaning and strongly leaning stems, respectively. In each section wound tissues formed after knife insertion are observed on three sides. Based on the wound tissue radial growth occurred after knife insertion (*i. e.* after leaning) can be recognized (Nobuchi et al. 1993).

All of the disks showed eccentric growth towards the upper side of the leaning stem. The degree of eccentric growth, however, was different among species. *Hevea* showed typical eccentric growth. *Hopea* also showed eccentric growth but the degree was not so great as *Hevea*. In *Shorea* lateral and opposite sides revealed very limited radial growth during three months after leaning of stems. Although the degree of eccentric growth was different among species, upper (or tension) side of all species surely showed accelerated radial growth after the treatment. In this research, therefore, it was assumed that tension side formed tension wood in wide sense.

In transverse sections a feature of vessel (pore) density was coarsely observed (Photo. 4). In *Hevea* not much difference was observed before and after treatment. *Hopea* showed marked decrease of vessel density and *Shorea* revealed faint reduction after treatment. The detailed quantitative analysis was carried out using image analyzing system.

In the comparison of disks between strongly and weakly leaning stems, no positive difference was observed. In the anatomical investigation disks of strongly leaning stems were exclusively observed.

3. 2. Tension wood anatomy

Light microscopic observation of tension (upper) side wood formed before treatment, lateral and opposite woods revealed no positive difference among them. Therefore, tension side wood formed before the treatment was adopted as a control or normal wood.

Photo. 5a shows a light micrograph of transverse section of *Hevea* which include portions formed both before and after the treatment. In Photo. 5a, tension wood was also observed even in the wood formed before leaning treatment. It shows that this species easily form tension wood. After leaning vessel density showed not much difference from control but vessel size decreased. In tension wood fibers formed typical G-layer, which appeared green with safranin and fast green staining (Photo. 7a) and deep purple with zinc chloride-iodine (Photo. 8a). These staining reaction revealed that degree of lignification was very low or almost zero.

Photo 5b shows a light micrograph of a transverse section of *Hopea* which includes portions formed both before and after the treatment. After leaning vessel density clearly decreased. Vessel size, however, showed not much reduction. Cell wall thickness of fibers was of similar size as control (Photo. 6b). However, thin inner layer showed strong green with safranine and fast green (Photo. 7b) and purple with zinc chloride-iodine (Photo. 8b), which revealed low degree of lignification. Under a polarization microscope thin inner layer in transverse section did not appear bright. The thin inner layer in radial longitudinal section showing purple color (Photo. 9b) appeared bright when examined between crossed nicols.

Fibers of *Hopea* were considered not to form typical G-layer but to form thin unlignified (or low degree of lignification) layer whose microfibril orientation was almost parallel to the cell axis.

Photo. 5c shows a light micrograph of a transverse section of *Shorea* which include portions formed both before and after the treatment. As already mentioned, the wood formed after the treatment was very much limited. Although vessel density showed almost no change after leaning, vessel size appeared slightly reduced. In cell wall organization of fibers *Shorea* revealed similar pattern as that of *Hopea*. However, innermost thin layer which showed green with safranin and fast green staining and purple with zinc chloride-iodine appeared very faintly bright in transverse section between crossed nicols. It was, therefore, considered that the microfibril orientation of the innermost thin laye would not be parallel to the cell axis but would have a certain degree to the axis.

In *Shorea* fiber diameter reduced after leaning (Photos. 6c and 7c). In *Hopea* (Photos. 7b and 8b) and *Shorea* (Photos. 7c and 8c) cell arrangement also changed to irregular pattern compared to control or normal (Photos. 6b and 6c). After leaning it was considered that intrusive growth of fibers occurred more frequently.

From the microscopical investigation it was clarified that *Hevea* formed typical tension wood with thick G-layer in fibers and *Hopea* and *Shorea* formed no typical tension wood. The detailed cell wall organization of species investigated including type of secondary wall (Wardrop and Dadswell 1955) is the future research point.

3. 3. Quantitative analysis of anatomical characteristics

To investigate tension wood characteristics in more detail quantitative analysis of average vessel area (Fig. 1), density of vessels (Fig. 2) and percentage of vessel area (Fig. 3) were performed. Figures. 1, 2, and 3 include data of both weakly and strongly leaning stems.

In *Hevea* vessel density did not change but vessel size decreased, which resulted in the reduction of the percentage of vessel area in transverse section. In *Hopea* it was revealed that vessel size did not decrease but vessel density strongly decreased resulting in the decrease of the percentage of vessel area. *Shorea* showed slight decrease of both vessel size and density resulting in the decrease of the percentage of vessel area. No positive difference between strongly and weakly leaning stems were found out.

From the quantitative analysis it was clarified that the percentage of vessel area decreased in three species investigated. As the general characteristics of tension wood, eccentric growth, fibers with thick G-layer, decrease of the degree of lignification and the decrease of the percentage of vessel area are recognized (Côté et al. 1965). The degree of the percentage of vessel area corresponds to the increase of the percentage of fibers. The increase of fiber percentage together with the formation of thick G-layer without or low lignification plays an important role for the recovery of a leaning stem towards the upright position through the mechanical force of shrinkage in the tension (or upper) side of leaning stem generated in the process of rearrangement of microfibrils (Wardrop 1965). In *Hevea* it was revealed that typical tension wood was formed. In *Hoepa* and *Shorea* fibers did not form typical G-layer though the percentage of fibers increased.

Onaka (1949) reported some species which did not form typical G-layer. Those species are of trees in temperate zone. The present investigation revealed that some tropical tree species did not form typical G-layer. From the view point of the mechanical force to change leaning stem to upright position, it would be possible that leaning stems of *Hopea* and *Shorea* would not recover to the upright position.

Family Dipterocarpaceae belongs to order Theales. In the report of Onaka (1949) some species such as *Camellia japonica, C. sinensis, Stewartia pseudo-camellia, Ternstroemia japonica* belonging to Theaceae were investigated. Those species showed eccentric growth towards upper side of stems. Fiber walls were classified as type II-I, where type II had thick G-layer and type I showed almost no increase of cell wall thickness. In type I the degree of lignification was

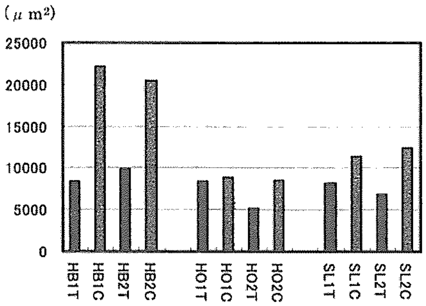

Fig. 1 Average vessel area (μm²).

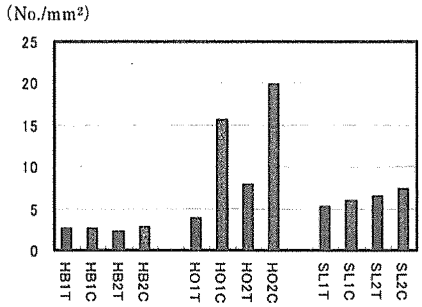

Fig. 2 Vessel density (No./ mm²).

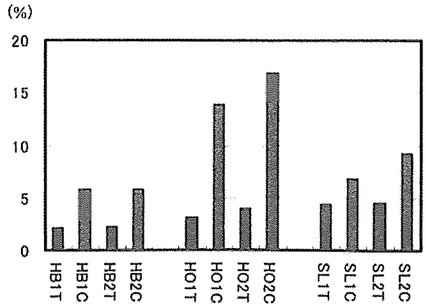

Fig. 3 Percentage of vessel area in transverse section.

gradually reduced towards lumen and finally innermost thin layer showed G-layer. The cell wall organization observed in *Hopea* and *Shorea* was considered to have similar tendency as Type I. In the future research of tropical trees including species belonging to Dipterocarpaceae, phylogeny is also the important view point.

In *Shorea* a new shoot came out from the leaning stem (Photo. 10). This phenomenon shows the possibility that the new shoot functions as a new leader of the tree substituted to the old leaning leader without recovering of the old stem to upright position.

It is considered that IAA moves to lower (or compression) side in a leaning stem. This uneven distribution of IAA is of the main cause of reaction wood formation especially in conifers (Wardrop 1965). In broad leaved trees real cause or trigger of tension wood formation is still under discussion. Baba et al. (1995) reported the importance of gibberellin to tension wood formation. If gibberellin would play an important role for tension wood formation, a certain amount of gibberellin would be used to form new shoots resulting in not enough distribution of gibberellin to form tension wood after leaning of stems in *Hopea* and *Shorea*.

Similar phenomenon of forming new shoots in a leaning stem was observed in tropical conifer species, *Agathis loranthifolia* in Indonesia (Nobuchi and Wahyudi). It is the future research point whether the formation of new shoots in leaning stems of tropical trees are popular or not. *Hopea* and *Shorea* belong to the family Dipterocarpaceae which is one of the dominant groups of tropical rain forest in Southeast Asia. It is important to investigate tension wood characteristics in wide range of trees in tropical forests.

As the conclusion of present preliminary study, *Hevea brasiliensis* formed typical tension wood, whereas *Hopea odorata* and *Shorea leprosula* showed no typical tension wood formation even under the condition of strongly leaning stems.

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